

Position Estimation

FIELD OF THE INVENTION

5 The invention relates to a method for estimating the position of a receiver receiving code modulated signals from at least one beacon. The invention relates equally to such a receiver, to a system comprising such a receiver and to a software program product in which a software code for
10 estimating the position of a receiver receiving code modulated signals from at least one beacon is stored.

BACKGROUND OF THE INVENTION

15 It is known in the state of the art to determine the position of a receiver based on code modulated signals from several beacons using, for example, a CDMA (Code Division Multiple Access) spread spectrum communication.

20 For a spread spectrum communication in its basic form, a data sequence is used by a transmitting unit to modulate a sinusoidal carrier and then the bandwidth of the resulting signal is spread to a much larger value. For spreading the bandwidth, the single-frequency carrier can be multiplied
25 for example by a high-rate binary pseudo-random noise (PRN) code sequence comprising values of -1 and 1, which code sequence is known to a receiver. Thus, the signal that is transmitted includes a data component, a PRN component, and a sinusoidal carrier component.

30 A well known system which is based on the evaluation of such code modulated signals is GPS (Global Positioning System). In GPS, code modulated signals are transmitted by several satellites that orbit the earth and received by GPS
35 receivers of which the current position is to be

determined. Each of the satellites, which are also called space vehicles (SV), transmits two microwave carrier signals. One of these carrier signals L1 is employed for carrying a navigation message and code signals of a
5 standard positioning service (SPS). The L1 carrier signal is modulated by each satellite with a different C/A (Coarse Acquisition) Code known at the receivers. Thus, different channels are obtained for the transmission by the different satellites. The C/A code, which is spreading the spectrum
10 over a 1 MHz bandwidth, is repeated every 1023 chips, the epoch of the code being 1 ms. The carrier frequency of the L1 signal is further modulated with the navigation information at a bit rate of 50 bit/s.

15 The navigation information, which constitutes a data sequence, comprises in particular ephemeris data. The ephemeris data comprises ephemeris parameters describing short sections of the orbit of the respective satellite. Based on these ephemeris parameters, an algorithm can
20 estimate the position of the satellite for any time while the satellite is in the respectively described section. The ephemeris data also comprises clock correction parameters which indicate the current deviation of the satellite clock versus a general GPS time. Further, a time-of-week TOW
25 count is reported every six seconds as another part of the navigation message.

A GPS receiver of which the position is to be determined receives the signals transmitted by the currently available
30 satellites, and a tracking unit of the receiver detects and tracks the channels used by different satellites based on the different comprised C/A codes. The receiver first determines the time of transmission TOT of the code transmitted by each satellite. Usually, the estimated time
35 of transmission is composed of two components. A first

component is the TOW count extracted from the decoded navigation message in the signals from the satellite, which has a precision of six seconds. A second component is based on counting the epochs and chips from the time at which the bits indicating the TOW are received in the tracking unit of the receiver. The epoch and chip count provides the receiver with the milliseconds and sub-milliseconds of the time of transmission of specific received bits.

10 Based on the time of transmission and the measured time of arrival TOA of the signal at the receiver, the time of flight TOF required by the signal to propagate from the satellite to the receiver is determined. By multiplying this TOF with the speed of light, it is converted to the distance between the receiver and the respective satellite. The computed distance between a specific satellite and a receiver is called pseudo-range, because the GPS system time is not accurately known in the receiver. Usually, the receiver calculates the accurate time of arrival of a signal based on some initial estimate, and the more accurate the initial time estimate is, the more efficient are position and accurate time calculations. A reference GPS time can, but does not have to be provided to the receiver by a network.

25 The computed distances and the estimated positions of the satellites then permit a calculation of the current position of the receiver, since the receiver is located at an intersection of the pseudo-ranges from a set of satellites. In order to be able to compute a position of a receiver in three dimensions and the time offset in the receiver clock, the signals from four different GPS satellite signals are required.

In urban and indoor environments, however, the number of found satellites may be less than four. Thus, it is a challenging task to estimate the position of a receiver based on incomplete information.

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It is known to use hybrid positioning systems, in which base stations and satellites are used in the positioning, but also such hybrid positioning systems require a certain amount of measurements. If there are not sufficient
10 measurements available, the measurements are discarded and new measurements are obtained.

The problem of missing measurements has been solved by freezing some of the coordinates of the receiver using
15 appropriate reference coordinates and by finding the solution of the usual equations only for the remaining coordinates. An information on the altitude is used in this approach when available. Such a freezing of coordinates may lead to large errors in certain situations, though.

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It is to be understood that the problem arises not only for GPS receivers, but as well with any other type of ranging receivers for which the position is to be calculated based on code modulated beacon signals.

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SUMMARY OF THE INVENTION

It is an object of the invention to determine the position of a receiver in situations in which the number of
30 available beacons is less than the minimum required by conventional methods.

A method for estimating the position of a receiver receiving code modulated signals from at least one beacon
35 is proposed. The proposed method comprises delimiting a

region containing the receiver position based on a code modulated signal received at the receiver from at least one beacon and on available information including at least an initial information on the receiver position. The proposed
5 method further comprises estimating the receiver position as a position within the delimited region which minimizes an error criterion.

Moreover, a receiver is proposed, which comprises for an
10 estimation of its position a receiving portion for receiving a code modulated signal from beacons. The proposed receiver further comprises a processing portion for delimiting a region containing said receiver position based on a code modulated signal received by the receiving
15 portion from at least one beacon and on available information including at least an initial information on the receiver position. The processing portion is adapted in addition for estimating the receiver position as a position within the delimited region which minimizes an error
20 criterion.

Moreover, a system for estimating the position of a receiver receiving code modulated signals from at least one beacon is proposed. The system comprises this receiver,
25 which includes a receiving portion for receiving code modulated signals from a beacon, and a device with a processing portion. The processing portion is adapted for delimiting a region containing the receiver position based on a code modulated signal received by the receiving
30 portion from at least one beacon and on available information including at least an initial information on the receiver position, and for estimating the receiver position as a position within the delimited region which minimizes an error criterion.

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The proposed system can be realized in several ways, some of which are presented by way of example. The device of the proposed system may include the receiver or be connected to the receiver, the combination of the device and the
5 receiver forming the proposed system. In both cases, the device can be for example a mobile terminal which is able to communicate with a mobile communication network for receiving information supporting the delimitation of the region of possible receiver positions. A network element of
10 the network may then be as well a part of the proposed system. Alternatively, the device of the proposed system can be itself a network element of a mobile communication network. If the receiver is then included in or connected to a mobile terminal, the information on received code
15 modulated signals can be transmitted by the communication functionality of the mobile terminal to the mobile communication network for evaluation by the network element.

20 Finally, a software program product is proposed, in which a software code for estimating the position of a receiver receiving code modulated signals from at least one beacon is stored. When running in a processing unit, the software code delimits a region containing the receiver position
25 based on a code modulated signal received at the receiver from at least one beacon and on available information including at least an initial information on the receiver position. Further, the software code estimates the receiver position as a position within the delimited region which
30 minimizes an error criterion.

The invention proceeds from the consideration that the respectively available measurements on beacon signals can be made use of independently of the amount of the
35 measurements, when initial information on the position of

the receiver and possibly some other information is used for limiting the region in which the receiver may be located and when a final position estimate is selected from this region by minimizing an error according to a certain
5 criterion. The resulting position may not be exactly correct, but the position can be determined immediately and its possible deviation from the true position is as small as possible.

10 It is an advantage of the invention that it allows to exploit the available information optimally. It allows in particular to estimate a reliable position of a receiver even if the number of available beacons is less than the minimum number required in conventional methods.

15 Initial information on the receiver position is available in many cases in form of a reference position. A reference position may be the position of a nearby base station of a mobile communication network or of another beacon. It may
20 also be estimated from previous position fixes of the receiver.

The error criterion which is minimized may be for example the maximum possible error, the mean absolute error or the
25 mean square error which results at a respectively selected position.

The invention can be implemented in particular, though not exclusively, in software.

30 The invention can be employed for the positioning of any type of ranging receiver receiving code modulated signals from any type of beacons, for instance for a receiver of a positioning system like GPS or Galileo receiving code
35 modulated signals from satellites.

Other objects and features of the present invention will become apparent from the following detailed description considered in conjunction with the accompanying drawings.

5 It is to be understood, however, that the drawings are designed solely for purposes of illustration and not as a definition of the limits of the invention, for which reference should be made to the appended claims. It should be further understood that the drawings are not drawn to
10 scale and that they are merely intended to conceptually illustrate the structures and procedures described herein.

BRIEF DESCRIPTION OF THE FIGURES

15 Fig. 1 schematically shows a positioning system in which an embodiment of the invention can be implemented;
Fig. 2 schematically shows an alternative positioning system in which an embodiment of the invention can be implemented;
20 Fig. 3 schematically shows a further alternative positioning system in which an embodiment of the invention can be implemented;
Fig. 4 illustrates a first situation in which an embodiment of the invention can be used;
25 Fig. 5 illustrates a second situation in which an embodiment of the invention can be used;
Fig. 6 illustrates a third situation in which an embodiment of the invention can be used;
Fig. 7 illustrates a fourth situation in which an
30 embodiment of the invention can be used; and
Fig. 8 is a flow chart illustrating an embodiment of the method according to the invention implemented in the system of one of figures 1 to 3.

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DETAILED DESCRIPTION OF THE INVENTION

Figure 1 schematically presents by way of example a GPS positioning system, in which the position of a GPS receiver
5 1 can be determined in accordance with the invention.

The positioning system comprises a mobile terminal 2 with the GPS receiver 1, a plurality of GPS satellites, of which two are shown as SV₁ 3 and SV₂ 4, and a network element 5 of
10 a mobile communication network 6.

The GPS receiver 1 includes a receiving portion 7 and a processing portion 8. The receiving portion 7 receives, acquires and tracks code modulated signals transmitted by
15 the GPS satellites 3, 4. Further, it performs measurements on the signals and extracts information included in the signals. The processing portion 8 uses a software 9 for estimating the position of the GPS receiver 1 based on information received from the receiving portion 7. For
20 estimating the receiver position, the processing portion 8 first determines a region which can be assumed to comprise the receiver positions and then estimates the true receiver position by minimizing an error criterion.

25 The mobile terminal 1 is able to communicate with the mobile communication network 6 in a known manner. Thereby, it is able to provide information made available by the network element 5 of the mobile communication network 6 to the processing portion 8 of the GPS receiver 1. Such
30 information may include for example information on the accurate GPS time, information on a reference location or information on the altitude in the radio cell in which the mobile terminal 1 is currently located.

Figure 2 schematically presents by way of example an alternative GPS positioning system, in which the position of a GPS receiver 1 can be estimated in accordance with the invention.

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The system corresponds mainly to the system of figure 1, and the same reference signs 1 to 9 were employed for corresponding components. In this case, however, the processing portion 8 using a software 9 for determining the position of the GPS receiver 1 is integrated within the mobile terminal 2, but outside of the GPS receiver 1. The receiving portion 7 of the GPS receiver 1 is nevertheless able to provide information on received GPS signals to the processing portion 8.

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Figure 3 schematically presents by way of example a further alternative GPS positioning system, in which the position of a GPS receiver 1 can be estimated in accordance with the invention.

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The system corresponds mainly again to the system of figure 1, and the same reference signs 1 to 9 were employed again for corresponding components. In this case, however, the processing portion 8 using a software 9 for determining the position of the GPS receiver 1 is integrated in the network element 5 of the mobile communication network 6 and thus even outside of the mobile terminal 2. The receiving portion 7 of the GPS receiver 1 is able to provide information on received GPS signals to the processing portion 8 of the network element 5 making use of the communication abilities of the mobile terminal 2.

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Figures 4 to 7 illustrate different situations, in which the position of the GPS receiver 1 can be estimated in any

of the systems of figures 1 to 3 in accordance with the invention.

For a first type of situations, it is assumed that the time
5 of the GPS receiver 1 is the accurate time of the GPS system. That is, the time of arrival of GPS satellite signals at the GPS receiver 1 can be determined accurately.

A possible situation of this first type is illustrated in
10 figure 4. In this situation, only signals from one GPS satellite SV_1 are received by the GPS receiver 1. In addition, a reference location R is known, for example in form of a previously fixed position of the GPS receiver 1. Alternatively, the reference location R may correspond to
15 the coordinates of the radio cell in which the mobile terminal 2 is currently located. Such coordinates may be provided to the mobile terminal 2 by the mobile communication network 6.

20 In the situation of figure 4, the possible positions of the GPS receiver 1 are located on a first sphere having its center at the position of the satellite SV_1 and having a radius which is equal to the distance d_{SV_1} between the satellite SV_1 and the GPS receiver 1. The position of the
25 satellite SV_1 is indicated to the receiver with the ephemeris data in the received satellite signal. The distance d_{SV_1} can be calculated accurately by the GPS receiver 1 in a known manner from the time of transmission and the time of arrival of a specific fragment of the
30 satellite signal, i.e. based on the information included in a received fragment and on measurements on this received fragment.

A second sphere around the reference location R indicates
35 the accuracy limits of the reference location R. These

accuracy limits and thus the radius d_R of the second sphere can be estimated in many situations by the GPS receiver 1.

The true position of the GPS receiver 1 thus has to be
5 located more specifically on the section (AB) of the first sphere which is comprised in the second sphere.

The receiver position P is estimated according to the invention within this section (AB) by minimizing an error
10 criterion, as will be explained further below with reference to figure 8.

Another possible situation of the first type is illustrated in figure 5. In this case, signals from two GPS satellites
15 SV_1 , SV_2 are received by the GPS receiver 1. In addition, a reference location R is known again.

In this case, the possible positions of the GPS receiver 1 are known to be located on the circular line resulting from
20 the intersection of two spheres centered at the location of respectively one of the two satellites SV_1 , SV_2 and having radiuses d_{SV_1} , d_{SV_2} defined by the distance between the GPS receiver 1 and the respective satellite SV_1 , SV_2 .

25 A third sphere around the reference location R having a radius d_R indicates again the accuracy limits of the reference location R. The position of the GPS receiver 1 thus has to be located more specifically on the arc (AB) of the above mentioned circular line which is comprised in the
30 third sphere.

The receiver position P is estimated according to the invention from positions on this arc (AB) by minimizing an error criterion, as will be explained further below with
35 reference to figure 8.

For a second type of situation, it is assumed that the time of the GPS receiver 1 is not accurate, but that the limits of the accuracy of the time are known. That is, the time of arrival of GPS satellite signals at the GPS receiver 1 can be determined only with a limited but known accuracy.

The time inaccuracy has a linear shifting effect on the range measurements at the GPS receiver 1, as the distance between the GPS receiver 1 and a satellite is derived from a multiplication of the speed of light and the difference between the time of transmission and the time of arrival of a satellite signal.

Still, an area of possible positions of the GPS receiver 1 can be found by taking into account the accuracy of the time measurement. To each possible time assumption, a region of possible positions is associated, and the sum of these regions constitutes the area of all possible positions.

In a possible situation of the second type, a reference location of a known accuracy is available, and the GPS receiver 1 receives signals only from a single satellite. In this case, the true receiver position is located in a region corresponding to a globe centered at the reference location with a radius determined by the accuracy of the reference location.

In a further possible situation of the second type, which is illustrated in figure 6, a reference location R including its accuracy is known, and signals from two satellites are received at the GPS receiver 1.

Proceeding from a specific, even though inaccurate, time of arrival of the signals of both satellites, two spheres can be obtained, which are centered at the location of one of the two satellites, respectively, and which have a radius
5 calculated based on the time of transmission and the time of arrival of the signals from the corresponding satellite. As in the situation illustrated in figure 5, the intersection of the two spheres results in a circle line. If the assumed time of arrival is varied, then the radiuses
10 of the spheres and thus the circle line vary as well.

When combining the circle lines resulting with all possible time assumptions for the time of arrival of the satellite signals, a surface S is obtained, which has to comprise the
15 correct receiver position. In figure 6, a part of a hose-shaped surface S having a cross section CS is depicted. The final region of possible positions is then the portion AB of this surface S lying within a globe centered at the reference location R and having a radius d_R according to its
20 accuracy.

The receiver position P is estimated according to the invention from positions in this region AB by minimizing an error criterion, as will be explained further below with
25 reference to figure 8.

In a further possible situation of the second type, which is illustrated in figure 7, a reference location R including its accuracy is known, and signals from three
30 satellites are received at the GPS receiver 1.

If the number of satellites is three, then there is one possible position defined in the three-dimensional space for each time assumption. Combining these possible
35 positions for all possible time assumptions leads to a

curve C on which the receiver position has to be located.
The section (AB) of this curve lying within the globe
centered at the reference location R and having a radius d_R
according to its accuracy constitutes the region of
5 possible positions.

The receiver position P is estimated according to the
invention from positions in this section (AB) by minimizing
an error criterion, as will be explained now with reference
10 to figure 8.

Figure 8 is a flow chart illustrating the estimation of the
GPS receiver 1 in the processing portion 8 of any of the
systems of figures 1 to 3.

15 In a first step, the processing portion 8 determines an
uncertainty region. The uncertainty region is the region in
which the GPS receiver 1 has to be located according to
available information. The uncertainty region is determined
20 more specifically based on available information about a
reference location R and on information received from the
receiving portion 7 about the signals from at least one
satellite SV_1 , SV_2 , as described above for the situations
illustrated in figures 4 to 7.

25 The uncertainty region is then covered by a grid. Each of
the grid points S_g , with $g = 1$ to m , is considered as
another possibility for the receiver position. m is the
number of grid points in the grid. The coarseness of the
30 grid is defined by the required accuracy of the final
solution.

For each grid point S_g , the distance to all available
satellites or to the strongest satellites SV_i , with $i = 1$ to
35 n , is determined. n is the total number of the considered

satellites. Based on the determined distance, the time of flight $T_{TOF,i}$ of signals propagating from a respective satellite SV_i to the position of the respective grid point S_g is calculated for each of the satellites SV_i . The time of transmission $T_{TOT,i}$ of the signals received at the GPS receiver 1 from all considered satellites SV_i is known from measurements in the receiving portion 7 of the GPS receiver 1. The time of arrival $T_{TOA,i}$ of the signals from each of the satellites SV_i at the location of the respective grid point S_g is estimated according to the following equation:

$$T_{TOA,i} = T_{TOT,i} + T_{TOF,i}.$$

For each grid point S_g , the matching of the reception time is estimated from all determined times of arrival by estimating the matching error ME according to the following equation:

$$ME = \sum_{\substack{\text{all } i,j \\ i < j}} |T_{TOA,i} - T_{TOA,j}|$$

For the matching error ME, an acceptable threshold value ME_{\max} is predefined. If the determined value ME is smaller than the threshold value ME_{\max} for a particular grid point S_g , and if the position of the grid point S_g satisfies all other possible conditions, then this grid point S_g is included in a list of all possible solutions S_{list} . The mentioned other possible conditions may be for example a knowledge about the altitude, etc. If such additional information is considered, the position estimate will be more accurate.

When all grid points S_g have been evaluated and either been added to the list S_{list} or been discarded, the receiver position $S_{solution}$ is estimated by selecting one of the grid

points from the list S_{list} as receiver position. When a grid point S_0 is selected from the list S_{list} as estimate for the receiver position, the maximum error corresponds to the distance between the selected grid point S_0 and the grid point in the list S_{list} having the largest distance to the selected grid point S_0 . The receiver position $S_{solution}$ can thus be estimated for example by finding the minimum of the maximum error according to the following equation:

$$10 \quad S_{solution} = \operatorname{argmin}_{S_0 \in S} \left(\max_{S \in S_{list}} |S_0 - S| \right)$$

It has to be noted that the solution could also be search outside of the list of possible solutions S_{list} .

15 In general, the receiver position $S_{solution}$ can be estimated among all positions s considered to be possible according to the following equation:

$$S_{solution} = \operatorname{argmin}_{s_0} \left(\max_{all\ possible\ s} |s_0 - s| \right)$$

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In some cases, a probability density function p will be known, which associates to each possible position s a probability density $p(s)$. In this case, the error criterion advantageously considers as well this probability density function. This can be realized for example by minimizing the mean square error according to the following equation:

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$$S_{solution} = \operatorname{argmin}_{s_0} \int_{all\ possible\ s} (s_0 - s)^2 p(s) ds$$

30 or the mean absolute error according to the following equation:

$$S_{\text{solution}} = \underset{s_0}{\operatorname{argmin}} \int |s_0 - s| p(s) ds$$

all possible s

It is to be understood that other known mathematical methods for minimizing an error criterion can be used as
5 well for estimating the position of the GPS receiver 1.

If the maximum possible error is minimized in the situation of figure 4 without consideration of any other possible conditions, then the estimated receiver position P will be
10 the projection of the reference location R onto the sector of the first sphere bounded by (AB).

If the maximum possible error is minimized in the situation of figure 5 without consideration of any other possible
15 conditions, then the estimated receiver position P will be the projection of the reference location R onto the arc bounded by (AB).

If the maximum possible error is minimized in the situation
20 of an inaccurate time and a single satellite without consideration of any other possible conditions, the estimated receiver position is the position of the reference location. The accurate time can then be calculated from the range between the reference location
25 and the satellite position.

The estimated receiver position P resulting in the situation of figure 6 based on the minimum of the maximum possible error without consideration of any other possible
30 conditions is indicated in figure 6 in the portion AB of the surface S.

The estimated receiver position P resulting in the situation of figure 7 based on the minimum of the maximum

possible error without consideration of any other possible conditions, is indicated in figure 7 in the section bounded by (AB) of the curve C.

- 5 On the whole, it becomes apparent that the invention provides a possibility of estimating a receiver position with a good reliability even when only signals from a limited number of GPS satellites are available.
- 10 While there have shown and described and pointed out fundamental novel features of the invention as applied to a preferred embodiment thereof, it will be understood that various omissions and substitutions and changes in the form and details of the devices and methods described may be
- 15 made by those skilled in the art without departing from the spirit of the invention. For example, it is expressly intended that all combinations of those elements and/or method steps which perform substantially the same function in substantially the same way to achieve the same results
- 20 are within the scope of the invention. Moreover, it should be recognized that structures and/or elements and/or method steps shown and/or described in connection with any disclosed form or embodiment of the invention may be incorporated in any other disclosed or described or
- 25 suggested form or embodiment as a general matter of design choice. It is the intention, therefore, to be limited only as indicated by the scope of the claims appended hereto.